

A REFERENCE MODEL FOR SPACE DATA SYSTEM INTERCONNECTION SERVICES

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ABSTRACT

The widespread adoption of standard packet-based data communication protocols and services for spaceflight missions provides the foundation for other standard space data handling services. These space data handling services can be defined as increasingly sophisticated processing of data or information received from lower-level services, using a layering approach made famous in the International Organization for Standardization (ISO) Open System Interconnection Reference Model (OSI-RM). The Space Data System Interconnection Reference Model (SDSI-RM) incorporates the conventions of the OSI-RM to provide a framework within which a complete set of space data handling services can be defined. The use of the SDSI-RM is illustrated through its application to data handling services and protocols that have been defined by, or are under consideration by, the Consultative Committee for Space Data Systems (CCSDS).

Key Words: Space communications, CCSDS, telemetry, telecommand, ISO/OSI

1. INTRODUCTION

Over the past decade, the world community of civilian space agencies has fostered the evolutionary adoption of standards for operational space data communication systems. Early efforts at standardization concentrated on the transfer of data across the space-ground radio frequency (RF) link. These efforts resulted in a packet-based statistical multiplexing alternative to time division multiplexing (TDM); powerful forward error correction for telemetry; and a reliable command delivery protocol. These standard mechanisms are documented in the CCSDS Recommendations for Packet Telemetry (Ref. 1) and Telecommand (Refs. 2 - 4).

Prompted by the prospect of an international space station containing hundreds of instruments and platform control functions communicating with a world-wide user community on the ground, CCSDS extended the scope of standardization. The expanded-scope services and protocols, documented in the CCSDS Recommendation for Advanced Orbiting Systems (AOS) (Ref. 5), comprise (a) an

expanded suite of space link services and protocols (e.g., bitstream, isochronous insert), and (b) end-to-end data transfer services (e.g., onboard instrument to ground-based telescope workstation). The AOS Recommendation introduces the concept of the CCSDS Principal Network (CPN), which is the concatenation of onboard, space link, and ground subnetworks.

The aforementioned CCSDS Recommendations were developed by starting at the space-ground link and working out. This "RF link out" approach is in contrast to that taken in the development of Open System Interconnection (OSI), an initiative of the International Organization for Standardization (ISO) which was to create a suite of services and protocols that would allow application programs on any two arbitrary end systems (aka nodes) to communicate. The OSI services and protocols have been created on the framework of the OSI Reference Model (OSI-RM) (Ref. 6). The OSI-RM allocates the functions of data communication to the now-famous seven layers: physical, data link, network, transport, session, presentation, and application. Because the OSI-RM addresses the complete range of functions that must be performed to allow two applications to communicate, the developers of the specific services and protocols at each layer were able to identify and mitigate overlaps and shortcomings within the suite of services/protocols.

Such a model for the interconnection of application processes is not limited to OSI services and protocols. In the context of space data systems, such a model could be used to:

- Provide a framework within which all aspects of space data interchange can be identified
- Identify which aspects of space data interchange are suitable to standardization
- Consolidate fundamental concepts for analysis of the data and information processing requirements of space missions
- Foster a terminology common to the space data and information handling community
- Provide the overall context that allows the standardization effort to proceed in multiple "narrower" activities better suited to the time and resource limitations of the standardization process

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Highlight data and information handling requirements common to space-based and ground-based systems, and thus foster the application of approaches and technologies common to both.

This paper introduces such a model, called the Space Data System Interconnection Reference Model (SDSI-RM). The scope of the SDSI-RM encompasses all communications between user applications exchanging space-related data.

The SDSI-RM is a synthesis of several recent space data system modeling activities: the CCSDS ground infrastructure reference model used in the development of CCSDS-standard ground infrastructure services (Ref. 7); a reference model for the European Space Agency (ESA) Space Data Network developed by Theis (Ref. 8); and a space mission interconnection model being developed for cross-support services between the Goddard Space Flight Center and the Jet Propulsion Laboratory (Ref. 9). These recent modeling efforts focus on different subsets of the overall space data communication problem, and do not address certain communication profiles (such as inter-spacecraft communications) and classes of service (such as end-to-end protocols and services). The goal of the SDSI-RM is to abstract the essential features common to these other models, and to provide the conceptual framework for defining the currently missing profiles and classes.

Owing to the introductory nature and brevity of this paper, the SDSI-RM as presented here glosses over a variety of rough edges that surface through detailed analysis. The intent here is to present the core features of the SDSI-RM.

2. SDSI-RM CONCEPTS AND TERMINOLOGY

The SDSI-RM adopts concepts and terminology of the OSI-RM, and augments those as necessary.

At the highest level, the SDSI-RM is partitioned into *architectural profiles*. These profiles correspond to major scenarios for the interconnection of space data-handling systems. Each architectural profile is defined in terms of the telecommunication services that interconnect two *user applications*.

User applications are part of, or attached to, *end systems*. Through the cooperation of *service entities* on each of the end systems, a telecommunication service is provided between the user applications. The telecommunication services are provided in a layered manner: a service entity in one end system exchanges service data and protocol information with its peer service entity in the other end system by using the service offered by the layer below. The

service entity at a given layer is simultaneously the *provider* of a service to the layer above, and a *user* of the service provided by the layer below, with each successive service layer adding value to the service provided by the layer below. This layering approach is successively applied from the medium that physically connects the end systems up to the user applications.

The case where two end systems are physically connected by a single physical medium is a special one. In the more general case, one or more *intermediate systems* lie between the end systems. An intermediate system is used to interconnect across multiple subnetworks, and/or when a service/protocol conversion is necessary between end systems.

The services within each architectural profile are grouped into *service classes*. Service classes are groupings of functionally-related services. A service class may be decomposed into more-specific, more narrowly defined subclasses. At the bottom of the subclassing hierarchy are concrete services (e.g., ISO Connectionless Transport Service (Refs. 10 & 11) using Transport Protocol class 4 (Ref. 12)). In most cases such concrete services have not yet been specified. For those cases, the SDSI-RM provides a place holder for requirements against to-be-specified services and protocols.

The specification of the different service classes within an architectural profile is based primarily on layer functionality vis-a-vis the OSI seven-layer model. However, classification by OSI layer alone does not address the different contexts in which those services are used. For example, the same transport service may be used to connect two end systems directly (an end-to-end context), and also be used to connect an end system to an intermediate system (a subnetwork context). The SDSI-RM classes reflect these contexts, and it is possible for the same services to appear in several service classes with the same architectural profile.

There are four architectural profiles in the SDSI-RM: space-ground, inter-spacecraft, terrestrial, and intra-spacecraft. The space-ground architectural profile is the focus of most modeling efforts, so it will be presented first and in the greatest detail.

3 SPACE-GROUND ARCHITECTURAL PROFILE

The space-ground architectural profile deals with interactions between space-borne and ground-based user applications. The space-borne user applications may be sensors, platform control systems, or, in the case of human-occupied spacecraft, astronauts or cosmonauts. The ground-based user applications that

communicate with the space-borne applications include science data handling systems, telescience, platform control center processes, and ground controllers.

The space-ground architectural profile contains seven top-level service classes:

- CPN Communication services class
- CPN Transport services class
- CPN Internet services class
- Space Link Access services class
- Space Link services class
- Terrestrial Telecommunication services class
- Spacecraft Telecommunication services class

Figure 1 illustrates the space-ground architectural profile, where the service classes are represented as boxed groupings of corresponding service elements.

3.1 CPN Communication Services Class

The CPN Communication services class provides the interconnected user applications with services associated with the OSI-RM's session, presentation, and application layers. These services are realized through the interaction of peer entities directly associated with the communicating user applications. The CPN Communication services class contains three subclasses: the ISO/OSI Communication services class, the Space Operations services class, and the Space Information Interchange services class.

The ISO/OSI Communication services class consists of a set of specific ISO-standard services and protocols at the application, presentation, and session layers. This suite is available for flight projects with requirements for OSI compliance. The ISO/OSI Communication services use the ISO/OSI Transport service class of the CPN Transport services class (see 3.2).

While the ISO/OSI communication services class provides many services of potential use in space flight operations, a growing body of evidence shows that use of the ISO/OSI protocols across a space-ground link may provide unacceptable performance in many operational scenarios. The Space Operations Communication services class is intended to provide a set of information transfer services equivalent to those of the ISO/OSI Communication services class, but modified for optimal performance in the space operations environment. The Space Operations Communication services class does not now exist, but CCSDS is contemplating a program of work to develop such a suite. Candidates for early development are a space-optimized file transfer service/protocol and commanding service/protocol. The Space Operations Communications services use

the Space Operations Transport service of the CPN Transport services class (see 3.2).

The Space Information Interchange services class comprises application- and presentation-layer services constructed around the CCSDS Standard Formatted Data Unit (SFDU). The SFDU is the currency of a standard system for encapsulating information in a way that enhances the identifiability, locatability, and archivability of that information. The Space Information Interchange services support the creation, cataloging, packaging, locating (finding), browsing, evaluation, and retrieval of SFDUs.

The Space Information Interchange services are currently being defined within CCSDS. As currently modeled in the SDSI-RM, the Space Information Interchange services can use the services of either the ISO/OSI or Space Operations Communication services class (or both) to connect across the space-ground link.

3.2 CPN Transport Services Class

The CPN Transport services class transfers data across the multiple subnetworks between the space-based and ground-based application processes, while providing the level of reliability that is required by the communicating user applications. The CPN Transport services class contains two subclasses, the ISO/OSI Transport service (Refs. 10 & 11) and the Space Operations Transport service.

The ISO/OSI Transport service is available for flight programs requiring OSI compliance. The ISO Transport service uses the CPN Internet service (see 3.4).

The Space Operations Transport service is a transport service (with supporting protocol) tailored to the space-ground telecommunication environment. The Space Operations Transport service and corresponding protocol do not now exist, but CCSDS will begin a program of work to develop them in the near future. The current thinking is that the Space Operations Transport service will use the CCSDS Path service of the Space Link Access services class (see 3.3) to provide an internetwork connection between the space-based and ground-based end systems.

3.3 Space Link Access Services Class

The Space Link Access (SLA) services class allows application processes that are remote from the termination of the space link to access the Space Link Services (see 3.5) that are provided at that link

termination. The SLA services provide access to Space Link service data in real-time and on a delayed-delivery basis.

The model of SLA services described in this paper actually addresses the simple case of providing SLA services when all of the Space Link service protocol processing is performed at the space link terminal. A general model of the SLA services exists which incorporates distribution of Space Link service protocol processing. The simple-case model described here is a subset of that general model.

Within the space-ground architectural profile, the SLA services class contains two subclasses, the Ground-based SLA (GSLA) services class and Space-based SLA (SSLA) classes. While the SSLA and GSLA services classes provide conceptually equivalent services, they differ in the specific characteristics of those services and the protocols used to provide those services. These differences arise from differences in the environments: the closed, local-area-networked, single-management-domain environment of the spacecraft vs. the relatively open, distributed, wide-area-networked, multiple-management-domain environment of the ground systems.

All but one of the SLA services are always accessed directly by the user application, without the use of intermediate CPN Communication or Transport services. These directly-accessed SLA services provide several different ways for moving mission-unique-format data between the space-based and ground-based user applications. The Path service (Ref. 5) does not always bypass the intervening layers: it provides a space-operations-optimized network service through the space link in support of Space Operations Transport and Space Operations Communication services. (The intervening layers may also be bypassed for Path service, so that the user applications may operate mission-unique communications and transport protocols through the Path service.)

The SLA services are provided by a client-server mechanism, with the server entity accessing Space Link Services in an intermediate system that terminates one end of the space link, and the client entity contained within the user application's end system. The GSLA server and client entities interconnect via Terrestrial Telecommunication services (see 3.6), and the SSLA server and client entities interconnect via Spacecraft Telecommunication services (see 3.7).

Standard GSLA services are currently under active development within CCSDS. The SSLA class is not being considered for multi-mission standardization at

this time. However, the SSLA class provides a reference model for individual flight programs to use in developing onboard service architectures that complement the services that will be encountered on the ground.

3.4 CPN Internet Service Class

The CPN Internet service class contains one concrete service, the CPN Internet service (Ref. 5), which provides the ISO Connectionless Network Service (Refs. 13 & 14) between the space-based and ground-based end systems. CPN Internet service entities exist in the two end systems, and in the intermediate systems containing the Space Link service entities.

3.5 Space Link Services Class

The Space Link services class supports the SLA services class by establishing and maintaining a data link between the ground infrastructure and the space infrastructure onboard a spacecraft. Collectively, the services in the Space Link services class:

- Establish and maintain the RF link between the ground and the mission spacecraft.
- Perform the protocol processing necessary to transfer various CCSDS-defined Space Link service data units across the space link.

The Space Link services are the services corresponding to the CCSDS Recommendations for AOS, Telecommand, and Packet Telemetry.

3.6 Terrestrial Telecommunication Services Class

In the context of the space-ground architectural profile, the Terrestrial Telecommunication services class provides telecommunication connectivity between the server and client entities of the GSLA services. The Terrestrial Telecommunication services class contains two subclasses, the Terrestrial Communication services class and the Terrestrial Transmission services class.

The Terrestrial Communication services class provides ISO/OSI services and protocols at the application, presentation, and session layers. The applicability of specific services within this class is under study. For example, File Transfer, Access, and Management (FTAM) (Ref. 15) is a candidate for use in transferring time-delayed files of space data between GSLA client and server.

The Terrestrial Transmission services class provides ISO/OSI services and protocols at the transport, network, data link, and physical layers. These services are used to support the Terrestrial

Communication services, and to provide ISO Transport and Network services for the transfer of real-time space data between GSLA client and server.

Selection of specific ISO/OSI services and protocols to support the GSLA services is a future item of work.

3.7 Spacecraft Telecommunication Services Class

In the context of the space-ground architectural profile, the Spacecraft Telecommunication services class provides telecommunication connectivity between the server and client entities of the SSLA services. The Spacecraft Telecommunication services class contains two subclasses, the Spacecraft Communication services class and the Spacecraft Transmission services class.

Conceptually, the Spacecraft Telecommunication services class provides ISO/OSI services and protocols offered in the Terrestrial Telecommunications services class, but specific services may differ from those selected for the ground network because of different requirements to support the SSLA services.

There is currently no work planned within CCSDS to standardize Spacecraft Telecommunication services or protocols.

4. INTER-SPACECRAFT ARCHITECTURAL PROFILE

The inter-spacecraft architectural profile deals with the communication between application-bearing spacecraft. An example is the communication between a free-flyer and Space Station or Shuttle during proximity operations. This profile is a simple variant of the space-ground profile, with another "space half" substituted for the ground half of the space-ground profile.

CCSDS is not currently working on this architectural profile.

5. TERRESTRIAL ARCHITECTURAL PROFILE

The terrestrial architectural profile deals with the communication of space-related data between two applications on the ground. This profile essentially consists of the Terrestrial Telecommunication services class found in the space-ground profile, augmented by the Space Information Interchange services class. The assumption that the terrestrial profile is populated by standard ISO/OSI protocols and services is basically a default position in lieu of any evidence that these standard services are

inadequate to the requirements. CCSDS is not currently working on this architectural profile.

6. INTRA-SPACECRAFT ARCHITECTURAL PROFILE

The intra-spacecraft architectural profile deals with communication between two applications onboard the same spacecraft. This profile essentially consists of the Spacecraft Telecommunication services class found in the space-ground profile, augmented by the Space Information Interchange services class. CCSDS is not currently working on this architectural profile.

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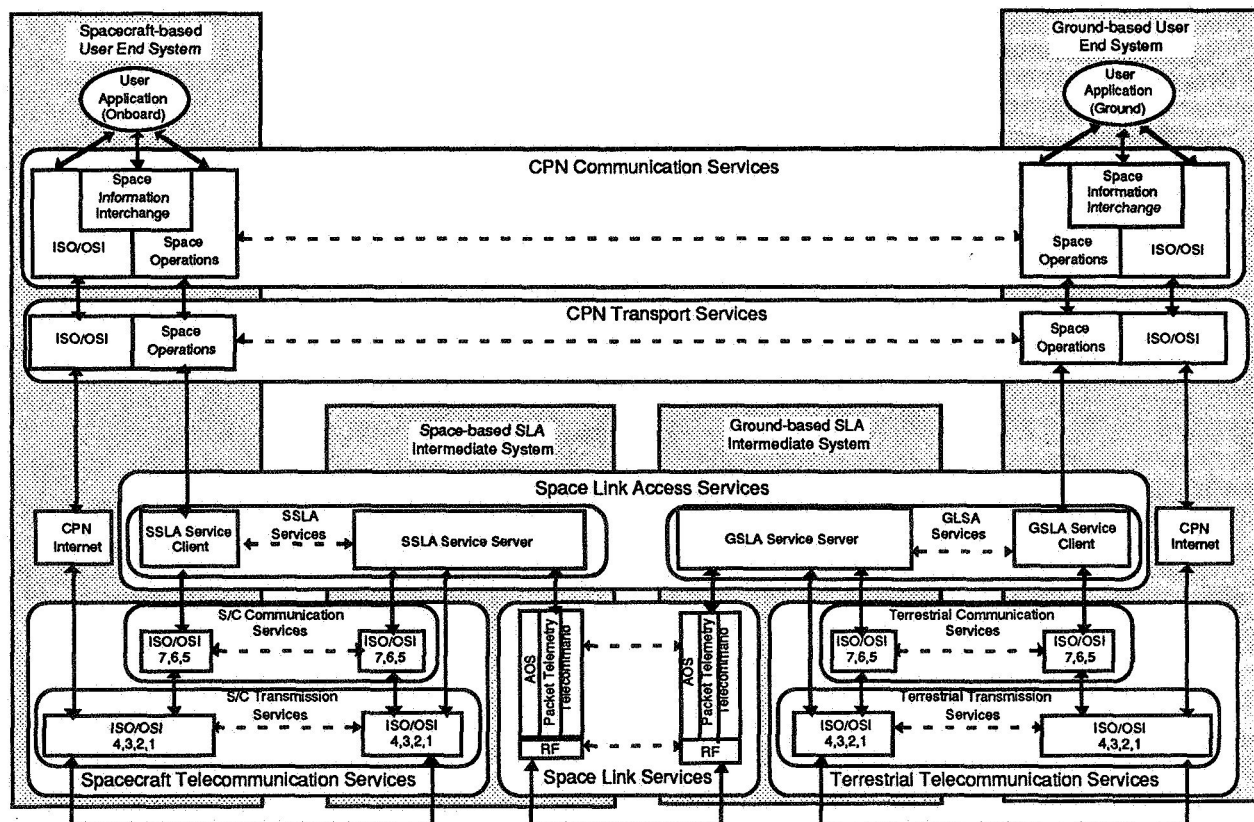


Figure 1. Space-Ground Architectural Profile